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XVII.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

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III.—INTENSITY OF TWILIGHT.

BY CHARLES H. WILLIAMS.

Read, May 11, 1875.

DURING the fall and winter of 1874 an attempt was made to measure the amount of light given by the sun when at different distances below the horizon. Days were chosen when the sky was perfectly clear at sunset, though a few observations were made when it was snowy or cloudy.

The instrument used was the photometer first described in the report of the Total Eclipse Expedition for 1870. It consisted of a box about five feet long, eighteen inches high, and twelve inches wide; over the top and sides, which were of light framework, black cloth was stretched; a circular hole, about five inches in diameter, was cut in one end and covered by a Bunsen disk, and a standard candle, in a spring candlestick, was moved along the centre of the box by means of a rod attached to it; the distance from candle to disk being varied at pleasure, and measured by a mms. scale attached to the rod.

It was found inconvenient in practice to be obliged to read the scale at every observation, and the disappearance of the spot could be better watched if the eyes were kept fixed on the disk. An arrangement for automatic registering was therefore added. A piece of sheet-iron connected the candlestick with a rod moving outside the box along its whole length, the iron clasped the rod and was held in place by friction; to the iron was fixed a movable point, which could be pressed into a fillet of paper by means of a string passing from the iron round a pulley at each end of the box. The position of the candle was varied by moving the rod; the point where the observation was taken was marked on the paper, and the distance of the candle from the disk in mms. was read off afterward from a scale.

To use the instrument, a suitable day being taken, the disk was exposed to the horizon a few minutes before sunset, the candle lighted, and placed at about fifty mms. from it. The disk was then watched until it became dark-centred; the distance of the candle from the disk was now adjusted, so that the centre of the disk should nearly disappear, when the time was noted, and observations were then taken every minute till the light became very feeble. It was found impossible to get a perfect disappearance of the spot, owing principally to the difference in color of the two lights, the candle being much more yellow than the sun; a certain neutral shade between the dark and light centre was therefore taken as the point for making the observations. Various attempts were made to get rid of this difference of color, but without success. A cell filled with a solution of sulphate of copper of different strengths was placed on the candle side of the disk, also indigo and other blue solutions; the only effect of these was to give the whole surface of the paper a greenish tint when the candle was brought near, without making the disappearance of the spot more perfect. Disks made of paper of different colors, and sheets of plaster of Paris, made extremely thin by pressing the fluid plaster between sheets of plate glass, were tried with the same results. The best material seemed to be fine white paper painted with spermaceti, except at the centre.

It seemed to make no difference in the relative diminution of the light, whether the observations were taken with a clear horizon or with part cut off by some adjoining building; the readings from the upper part of the building looking over the roofs agreeing very well with those taken below. Having made a number of observations on different days, the instrument was tested to get the probable error of any reading. The photometer was placed in a dark room and a fixed amount of daylight admitted, the candle was moved till the disk

TABLE I.

Distance.	Prob. E.	Percentage.
130 mm.	2. mm.	3
175 „	2.9 „	3
240 „	2.5 „	2
440 „	9.5 „	4
455 „	4.1 „	2
520 „	10. „	4
635 „	8.2 „	3
950 „	8.9 „	2

assumed the neutral tint, and the mean of ten readings taken. The amount of light admitted to the room was then increased, and eight sets of readings thus taken. The preceding table gives, in the first column, the mean distance of the candle from the disk for each series of ten settings; in the second, the probable error for each reading; and in the third, the percentage of error.

It will be seen that the probable error is not large enough to seriously invalidate the results of the observations, as the readings taken by the photometer denoted the distance at which a standard candle should be held from the disk to give a light equal to that from the sun at a given time; it was thought best to reduce those readings to some standard, and compare them with the light given by a standard candle burning at a distance of one metre from the disk. Suppose we wish to reduce a reading of 200 mms. to this standard, C, or 1,000 mms. Let $I =$ actual intensity: —

$$C : I = 200^2 : 1000^2 = \frac{1}{1000^2} : \frac{1}{200^2};$$

whence

$$I = C\left(\frac{1000}{200}\right) 2 = 25\,C.$$

In this way Table II. was constructed, giving the actual amount of light, the readings being taken every minute.

On the days represented in the first six columns, the observations were all taken with an unobstructed horizon. On Nov. 6 and 7, part of the sky was shut off by surrounding buildings. Jan. 15, there were a few clouds; and Jan. 3, the whole sky was overcast. Nov. 13, a cell with sulphate of copper solution was placed behind the disk; and on Dec. 31, a cell with solution of indigo was used.

To see whether the light decreased according to any function of the time, curves were constructed, taking for vertical distances the logarithm of the observed reading, and for horizontal distances the minutes after sunset at which the observations were made. The result gave a series of nearly straight lines all running in the same direction. In some of the lines, there was a decided bend in the middle, and traces of this were found in almost all. To make this bending more apparent, a residual curve was constructed; this was obtained by comparing each of the curves with a straight line drawn in their mean direction, and making the ordinates of the desired curve the mean of their differences from this straight line. In this way the deviation of the original curves from the straight line was made quite apparent, though the difference was not originally very great. To find the curve which should represent the diminution of the light for each minute after sun-

TABLE II.

Min'tes after Sunset.	Nov. 12.	Nov. 13.	Dec. 31.	Jan. 1.	Dec. 15.	Dec. 21.	Nov. 6.	Nov. 7.	Jan. 15.	Jan. 3.
1							237	177	27	7
2							204	149	25	6
3							204	135	21	6
4							188	114	19	5
5							177	108	16	4
6							149	98	13	4
7							139	91	12	3
8				164			132	81	10	3
9				144		156	121	74	9	2
10			174	125		141	114	64	7	2
11			161	121		134	100	54	6	1
12			144	106		125	89	43	5	1
13			141	104		118	81	37	4	
14			130	94		102	74	31	3	
15			102	77		83	63	26	3	
16	139		84	76		72	59	24	2	
17	132		76	63		59	48	20		
18	108	119	66	52		52	44	18		
19	98	96	?	41	46	45	34	15		
20	77	96	45	35	45	41	27	11		
21	69	69	35	32	39	35	23	10		
22	51	49	30	26	30	29	18	8		
23	46	?	26	23	26	25	15	6		
24	38	38	20	18	23	23	12	5		
25	31	30	17	15	19	20	10	4		
26	22	24	14	14	15	18	7	3		
27	16	20	11	10	11	14	4	3		
28	?	15	8	9	9	11	3	2		
29	13	12	?	7	8	10	3	2		
30	11	9	6	7	6	7	2	2		
31	9	7		5	5	7	2	1		
32	8	6		4	4	6	1	1		
33	6	5		4	?	5	1	.9		
34	4	4		3	3	4	1	.8		
35	?	3		2		3	.9	.6		
36	3	2		2		3	.7			
37	3	2					.7			
38	3	2								

set, the ordinates of the straight line were obtained, to these were added the ordinates of the residual curve for the same times after sunset, both readings being in logarithms of the original observations; this logarithmic sum was now doubled, the sign changed, and the figures so obtained were used as ordinates for a new curve, the abscissas being the times. From this last curve we obtain directly the logarithm of the number which would represent the proportion of light at any minute as compared with that at sunset, which we call unity.

In the following table the minutes after sunset, or abscissas, and the percentage of light as compared with sunset, or ordinates, are given, from which the last curve was constructed: —

TABLE III.

Minutes after Sunset.	Per cent of Light compared with Sunset.	Minutes after Sunset.	Per cent of Light.
0	1.000	18	.094
1	.950	19	.079
2	.817	20	.064
3	.752	21	.055
4	.655	22	.044
5	.597	23	.038
6	.516	24	.031
7	.466	25	.026
8	.407	26	.021
9	.337	27	.015
10	.290	28	.012
11	.261	29	.010
12	.228	30	.009
13	.200	31	.007
14	.177	32	.006
15	.143	33	.005
16	.128	34	.004
17	.101		

IV.—LIGHT OF THE SKY.

By W. O. Crosby.

The light of the sky is reflected light, of which the sun is the source.

It is well known that the light of the sky diminishes as the angular distance from the sun increases. And the following observations were made with a view, first, to determine the absolute amount of light received from the sky at different distances from the sun; secondly, to ascertain the law of the diminution of the light with increasing angular distance from the sun. The apparatus employed consisted of a common mirror, so arranged as to reflect the light horizontally into a darkened room, a condensing lens having an aperture of 9 cm. and a focal distance of 225 cm., and a photometer similar to that employed by Dr. Williams in his observations on twilight.

The method pursued was to so adjust the mirror and lens that an image of the sun would fall upon the disk of the photometer, and then